Z PLUS FOUR JETS PRODUCTION IN HADRONIC COLLISIONS

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Abstract

We present first results of $Z+4$ jet cross sections at the Tevatron $p\bar{p}$ collider with heavy quark flavor identification. The $Z+4$ jet channel is of particular interest as a normalizer for the $W+4$ jet background to top quark signals, as a background to a possible $t \rightarrow cZ$ flavor-changing neutral-current (FCNC) decay signal, and as a background to missing-p_T signals from gluino pairs. We also calculate the different heavy flavor contributions to $W+4$ jet production. The MADGRAPH program is used to generate all leading order subprocess helicity amplitudes. We present Monte Carlo studies with separation and acceptance criteria suitable for the Tevatron experimental analyses.

There are many potential new physics processes at hadron colliders, that would lead to final states with a weak boson plus multi-jets, where the weak boson is identified by its leptonic decay; these signals sometimes also contain a second weak boson, whose hadronic decay is less easily identified. Since a weak boson can also be produced along with gluon and quark jets, a knowledge of these QCD backgrounds is essential to the identification of new physics signals. Considerable effort has been devoted in recent years to the calculation of QCD $W+n$ jet ($n=1,2,3,4$) and $Z+n$ jet ($n=1,2,3$) cross sections; for the cases

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of high jet multiplicities n, that would be given by many interesting new physics signals, these calculations can currently be made at tree level only [1, 2, 3, 4]. We present first results for Z production with four QCD jets, evaluated for the Tevatron $p\bar{p}$ collider at $\sqrt{s} = 1.8$ TeV, including a separation of contributions from different heavy quark flavors. We also calculate $W + 4$ jets with heavy quark flavor identification; this goes beyond previous $W + 4$ jet results that flag only b-flavor[1].

Major areas of physics interest in a QCD Z+4 jet calculation are the following.
(a) The most immediate interest is in the top-quark searches at the Tevatron[5, 6]; the single-lepton signals have QCD W+4 jet production as the major background, and the W/Z ratio could provide a calibration. We calculate separate cross sections for different final-state jet flavors, to address the case of b-tagging.
(b) Possible isosinglet heavy quarks x would have both charged-current and neutral-current decay modes, with branching fraction ratios[7]

$$B(x \to qW) \;:\; B(x \to q'Z) \simeq 2 \;:\; 1. \tag{1}$$

(c) A related question is the possible existence of a prominent FCNC decay mode of the top quark[8], $t \to cZ$ along with the standard $t \to bW$ decay. This scenario leads to a $t\bar{t} \to (cZ)(bW) \to Z + 4$ jet signal, to be distinguished from QCD background.
(d) Supersymmetric particle production gives missing-p_T plus multijet signals at hadron colliders. In particular, gluino pairs $\tilde{g}\tilde{g}$ with decays $\tilde{g} \to \chi_1^0 q\bar{q}$ to the lightest neutralino χ_1^0 are expected to give missing-p_T plus 4 jets. Here $Z + 4$ jet production with $Z \to \nu\bar{\nu}$ is the major standard physics background; b-tagging is relevant, since there are regions of parameter space where $\tilde{g} \to t\tilde{t}$ or $\tilde{g} \to b\tilde{b}$ decays are dominant [9].

In our $Z + 4$-jet and $W + 4$-jet calculations, many Feynman diagrams must be expressed as amplitudes; e.g. $gg \to Zq\bar{q}gg$ involves 516 diagrams. This phase is accomplished by the MADGRAPH program[10], which generates all Feynman graphs and their helicity amplitudes, employing the HELAS approach[11]. We then fold in final phase space and initial parton distributions, using MRS set D'_-[12] evaluated at a scale $Q^2 = \langle p_T \rangle^2 + M_Z^2(M_W^2)$. For semi-realistic simulations, we make parton-level calculations of $p\bar{p} \to W(Z) + 4$ jets at $\sqrt{s} = 1.8$ TeV, treating final partons as jets if

$$p_T(j) > 20\,\mathrm{GeV},\;\; |\eta(j)| < 2,\;\; \Delta R(jj) > 0.4, \tag{2}$$

where $[\Delta R(jj)]^2 = [\Delta\eta(jj)]^2 + [\Delta\phi(jj)]^2$ defines the angular separation of jets. A correction must be made in comparing the parton transverse momentum p_T with the observed (uncorrected) jet transverse energy E_T; according to CDF simulations[5], typically 5 GeV or more must be added to the latter. The probability of b-tagging any particular final state depends on the separate probabilities

ϵ_j that any single jet $j = b, c, q/g$ satisfies the tagging criteria; we shall assume $\epsilon_b = 0.18$, $\epsilon_c = 0.05$ and $\epsilon_{q/g} = 0.01$, which approximate conditions in the CDF top-quark search[5].

When Z is detected by $Z \to e\bar{e}$ and W is detected by $W \to e\nu$, we take the electron and missing transverse momentum $\not{p}_T$ acceptance to be

$$\not{p}_T > 20 \text{ GeV} \quad (\text{for } W \text{ events}), \quad p_T(e) > 20 \text{ GeV}, \quad |\eta(\text{e})| < 1, \tag{3}$$

and require that electrons are isolated from jets by $\Delta R(ej) > 0.4$. These criteria approximate those used in Tevatron experimental analyses. In the following Z denotes $Z \to e^+e^-$ and W denotes $W^\pm \to e^\pm\nu$; with these leptonic branching fractions included, the total cross sections times branching fractions are denoted $B\sigma$, and we obtain $B\sigma(Z + 4\text{jet}) = 20.5$ fb, $B\sigma(W + 4\text{jet}) = 337$ fb . Separate cross sections in fb for the most important final jet-flavor configurations are:

b	c	q/g	$B\sigma(Z + 4\,\text{jets})$	$B\sigma(W + 4\,\text{jets})$
2	–	2	1.03	10.2
1	–	3	0.14	0.65
–	2	2	0.88	10.2
–	1	3	0.24	18.6
–	–	4	18.1	297

(4)

Folding in b-tagging efficiencies, the tagged cross sections are:

no. of tags	$B\sigma(Z + 4\,\text{jets})$	$B\sigma(W + 4\,\text{jets})$
≥ 0	20.5	337.
≥ 1	1.23	18.1
≥ 2	0.057	0.68
≥ 3	0.001	0.01

(5)

To compare with experimental event rates, one has to multiply these cross sections by efficiency factors for the electrons and muons and also take into account effects of detector simulations. However, these effects (together with theoretical uncertainties) are expected to cancel approximately in the ratio of $(W+4\text{jet})/(Z+4\text{jet})$ cross sections.

The predicted W/Z ratio in 4-jet events with at least one b-tag is about 14.7. This number is fairly insensitive to the jet threshold p_T cut. Even if we relax the p_T and η requirements on the fourth jet (as CDF does to increase statistics in the top-quark sample), this W/Z ratio remains about 14.

With 19.2 pb^{-1} luminosity, CDF finds two b-tagged $Z+4$ jet events and seven b-tagged $W + 4$ jet events, with relaxed E_T and η requirements on the fourth jet. Although the statistics are small, this observed W/Z ratio in 4-jet events appears to be anomalously low in comparison with the QCD prediction.

A more detailed discussion is presented in [13].

References

[1] F. A. Berends et al, Nucl.Phys. **B321**, 39 (1989), **B357**, 32 (1991).

[2] K. Hagiwara and D. Zeppenfeld, Nucl.Phys. **B313**, 560 (1989).

[3] V. Barger, T. Han, J. Ohnemus and D. Zeppenfeld, Phys. Rev. **D40**, 2888 (1989).

[4] Z. Kunszt, Nucl.Phys. **B247**, 339 (1984); M. Mangano, ibid **B405**, 536 (1993).

[5] CDF collaboration: F. Abe et al, FERMILAB-PUB-94/097-E.

[6] D0 collaboration: S. Abachi et al, Phys. Rev. Lett. **72**, 2138 (1994).

[7] For references see V. Barger and R.J.N. Phillips, MAD/PHYS/830 (1994).

[8] R. Barbieri and L.J. Hall, Nucl. Phys.**B319**, 1 (1989).

[9] H. Baer, M. Drees, C. Kao, M. Nojiri and X. Tata, FSU-HEP-940311.

[10] T. Stelzer and W. F. Long, Comp. Phys. Comm. **81**, 357 (1994).

[11] E. Murayama, I. Watanabe and K. Hagiwara, KEK Report 91-11, January 1992.

[12] A. D. Martin, R. G. Roberts, and W. J. Stirling, Phy.Lett.B **306**, 145 (1993);

[13] V. Barger, R. J. N. Phillips, E. Mirkes and T. Stelzer, MAD/PH/844, July 1994, to appear in Phys.Lett.B.